Indoor Confined Space: GNSS Multi-Frequency Location Method based on Pursuit Principle

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Abstract
Aiming at the problem that it is difficult to carry out effective high-precision positioning in the complex and limited indoor space environment, this paper proposes an indoor limited space GNSS multi-frequency PSO (Particle Swarm Optimization) positioning method. This algorithm effectively solves the positioning technical problems which caused by inaccurate indoor spatial signal ranging. further we analyze the factors that affect the performance of the positioning algorithm. Compared to our team's existing KPI-based doppler positioning algorithm, the algorithm in this paper improves the problem of inaccurate range measurement, which caused by frequent cycle slips of signal loss. Through multi-frequency coordination and local optimization processing, the stability and continuity of indoor high-precision positioning are improved. The simulation results of semi-measured data show that the accuracy of the positioning algorithm in this paper is equivalent to that of the existing algorithm. When some signals are temporarily lost and refilled, the performance of this algorithm is better than that of the existing algorithm, and it has better continuity and robustness.

Keywords
indoor environment, pseudolite , dual frequency, navigation and positioning, high precision, continuity

1. Introduction

With the full operation of the national Beidou system and the construction of the national comprehensive PNT (Positioning Navigation and Timing) network system, the construction of the indoor location service network is becoming more and more urgent. Of course, the relatively mature indoor positioning technology of the market [1-7]has two type, one is Ultra-wide band (UWB)[8,9]. The current market share of the technology is increasing year by year, showing good application prospects, but the technology still faces major bottlenecks in capacity and dedicated; another technology is array Bluetooth technology[10-12], Meter-level positioning accuracy can currently be achieved with AOA (Angle of arrival) technology, but further improvement is still needed in the high-density layout problem.

Compared with the above technologies, pseudo-satellite technology has three advantages: (1) flexible networking mode, fast networking in small scale and large scale space; (2) passive positioning, no user capacity problem; (3) highly compatible with GNSS system, to meet the seamless indoor and outdoor applications of the same terminal. Therefore, this paper still focuses on the pseudo-satellite technology compatible with navigation satellites. At present, Waseda University in Japan has conducted more extensive technical research on this direction[13-18], Low-speed and high-precision positioning in the indoor environment can be realized through the existing half-wavelength array pseudo-satellite technology, doppler and ambiguity repair technology. Based on the technical inspiration, China electric 54 put forward aa method ,which

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does not rely on half wavelength indoor homologous array pseudo satellite technology. On this basis, through the carrier phase application, implements the indoor carrier phase based on KPI (Known point initialization) doppler high precision positioning algorithm, based on electromagnetic map pseudo satellite fingerprint positioning technology, etc. It solves the problem of high-precision positioning in the indoor non-test environment[19-23]。

Combine the existing technical achievements. Facing the problem of initial point assignment, a combined location algorithm using multi-frequency constrained ranging and local optimization is proposed. By integrating the relationship between probability statistics and frequency and signal transmission characteristics, the problem of obtaining absolute ranging information in indoor environment is solved, and the method of indoor absolute location method is given.

2. Signal features

The base station signals analyzed in this paper are accomplished by homologous design. First, the time-frequency control module tamed the local clock in real time to ensure the clock output of 1PPS and reference clock 10 MHz consistent with GNSS. The reference clock realizes the generation of multiple frequency signals required for signal generation through the clock frequency division module. Under the control of 1PPS, the baseband signal modulation of each frequency is completed in the baseband signal generation module, and finally the RF signal combined circuit output is completed by the upconversion module. Since the signals between multiple channels and between different frequency points are controlled by the same PLL, so all signals have the same time-frequency characteristics. At the same time, for each frequency point signal transmitted on the same channel, because the hardware transmission path of each signal is the same, we can think that the device delay between the frequency point signals of the same channel is the same, so the multiple frequency point signals of each channel have a fixed phase relationship.The pseudo-satellite base station principle is shown in Figure 1.

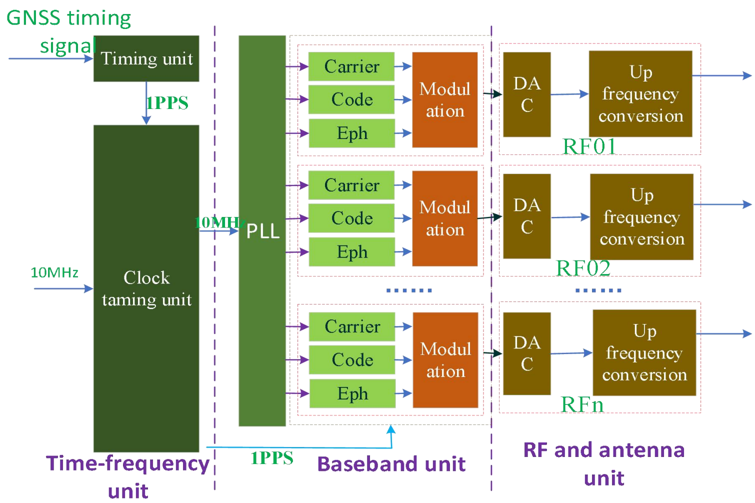

Figure 1: The pseudo-satellite base station principle

3. GNSS MFCR Localizatin Algorithm

3.1. Multi-frequency joint ranging

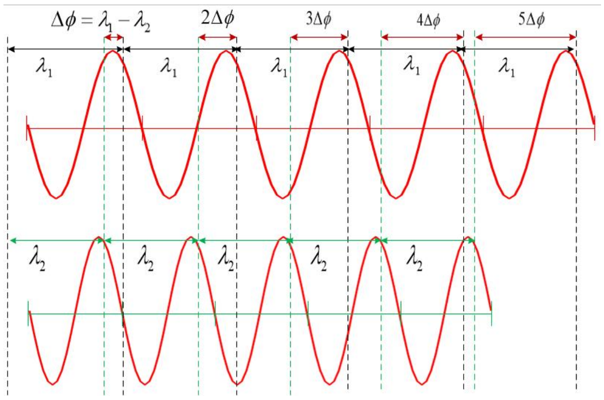

Figure 2: The principle of distance measurement

As shown in Figure 2, the multi-frequency ranging principle is similar to the pursuit principle. Assuming that on the circular track, A athletes run λ_1 within unit time Δt and B athletes run λ_2 within unit time Δt , then the AB distance varies $\Delta\phi = \lambda_1 - \lambda_2$ within unit time. Therefore, we can judge how far athletes A and B each run according to the cumulative change of the distance difference. According to this principle, we assume that the wavelengths of the two frequency points are also respectively, so we give the equation between the propagation distance and wavelength of the two frequency points is λ_1 and λ_2

$$\begin{cases} \Phi_1 = \lambda_1 * N_1 + \Delta\phi_1 - \Delta\phi_{init,1} + \xi_1 \\ \Phi_2 = \lambda_2 * N_2 + \Delta\phi_2 - \Delta\phi_{init,2} + \xi_2 \end{cases} \quad (1)$$

In the formula: Φ_1 and Φ_2 are the propagation distance of two frequency signals; λ_1 and λ_2 are the wavelength; N_1 and N_2 are the cycle count; $\Delta\phi_1$ and $\Delta\phi_2$ are the carrier phase of one cycle; ξ_1 and ξ_2 are the noise error value; $\Delta\phi_{init,1}$ and $\Delta\phi_{init,2}$ are two frequency point signal transmission initial phase distance value, assumed here is 0, then the formula can be simplified into:

$$\begin{cases} \Phi_1 = \lambda_1 * N_1 + \Delta\phi_1 + \xi_1 \\ \Phi_2 = \lambda_2 * N_2 + \Delta\phi_2 + \xi_2 \end{cases} \quad (2)$$

Thus, the double-frequency difference value can be obtained as follows.

$$\Delta\Phi_{21} = \Delta\phi_{21} + \lambda_2 * N_2 - \lambda_1 * N_1 + \xi_{21} \quad (3)$$

The pursuit principle is also available.

$$\Delta\phi_{21} = \mathrm{mod}((\lambda_2 - \lambda_1) * N_2, \lambda_1) \quad (4)$$

Assuming that the resulting integer value is M, then the upper formula can be changed to

$$\Delta\phi_{21} = (\lambda_2 - \lambda_1) N_2 - \lambda_1 M \quad (5)$$

$P = round(\frac{\lambda_1}{\lambda_2 - \lambda_1})$, P is the number of cycles to walk. $N_2 = MP$ .Then can be obtained

$$N_1 = \frac{\Delta\phi_{21} + \lambda_2 * \frac{\Delta\phi_{21} * (round(\frac{\lambda_1}{\lambda_2 - \lambda_1}))}{(\lambda_2 - \lambda_1)P - \lambda_1}}{\lambda_1} \tag{6}$$

Finally, we get the distance value. Φ_1 and Φ_2

3.2. Data integrity strategy

The data fusion processing strategy is shown in Figure 3.

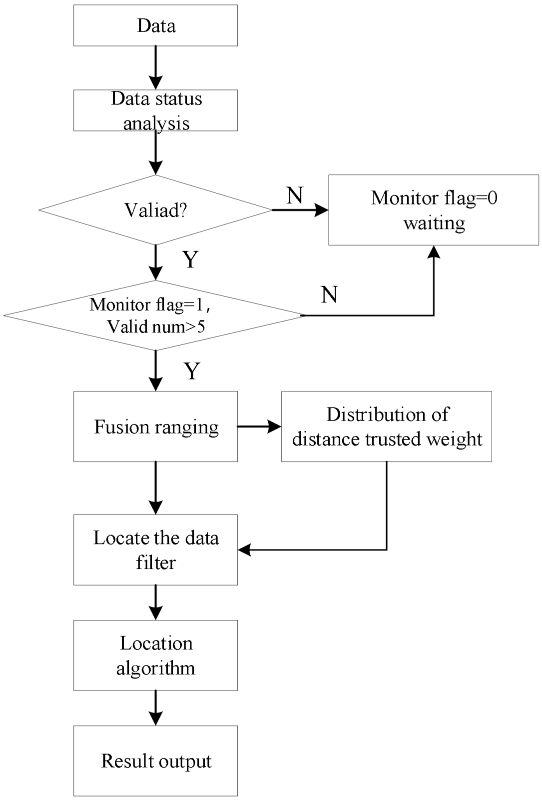

Figure 3: Data fusion processing strategy

3.3. Ranging fusion strategy

Assuming that when there are n frequency signals, in accordance with the selection C_n^2, then there are $n-1$ combination, each frequency ranging values have $n(n-1)/2$ times ranging values. Therefore, there are altogether $num = n(n-1)/2$ ranging results for the current position at the current moment. The distance between the transmitting channel and the receiving point can be estimated by one-dimensional normal sample expectation.

$$ps_j = \sum_{i=1}^{num} \Phi_{i,j} \Big/ num \tag{7}$$

Among them, j is the j channel, ps_j is the j channel signal to reach the receiving point of the evaluation distance value, $\Phi_{i,j}$ is the j channel signal to reach the i frequency point of the distance value.

3.4. The PSO location search

Based on the estimated speed of the maximum doppler value, and set the Doppler value as f_d, then the speed is v.

$$v = c * \frac{f_d}{f} \tag{8}$$

The search radius is defined as

$$r = \frac{2 * v}{iter} \tag{9}$$

Where iter is the output rate of raw observation data per second of the receiver in hz

If the position $\left(x_{k-1} \quad y_{k-1} \quad z_{k-1} \right)$ at the previous moment is given, the position at the current moment k is searched for

$$\begin{aligned} & x \in (x_{k-1}, x_{k-1} + r * \cos(\varphi) * \sin(\theta)) \\ & y \in (y_{k-1}, y_{k-1} + r * \cos(\varphi) * \cos(\theta)) \\ & z \in (z_{k-1}, z_{k-1} + r * \sin(\varphi)) \end{aligned} \tag{10}$$

The particle swarm optimization algorithm initializes the constants are c_1 c_2 r_1 r_2 and w. In the three-dimensional search space, there are a total of M particles forming a group, the i th particle space position is xi is the potential optimal solution of the optimization problem, the speed of the particle is recorded v_i ,the contemporary best position $p_{i,best}$, the historical best positio p_{best}, the n-1 generation particle, the velocity and position of the n generation equation is

$$\begin{aligned} & v_i^n = w v_i^{n-1} + c_1 r_1 (p_{i,best} - x_i^{n-1}) + c_2 r_2 (p_{best} - x_i^{n-1}) \\ & x_i^n = x_i^{n-1} + v_i^n \end{aligned} \tag{11}$$

Among them,the w is inertial weights; c_1 and c_2 are self-learning factor and group learning factor, respectively, taking positive values; r_1 and r_2 are two random numbers varying within [0,1].

4. Simution Validation

4.1. Simulation Setting

The simulation test is set based on the existing array pseudo-satellite platform. Here, L1C, B1I and B3I signals are selected for simulation. The signal characteristics are shown in the Table 1.

Table 1 The Signal Characteristics

name	frequency (Mhz)	tape width (Mhz)	modulation mode	PRN number
L1C	1575.42	2.046	B PSK	1~8
B1I	1561.098	4.092	B PSK	6~13
B 3I	1268.52	20.46	B PSK	6~13

During the indoor application of pseudo satellite signals, frequent recatch usually occurs, which will introduce cycle jump. Based on the existing phenomenon, the simulation conditions are set as follows:

1. The simulation time is 100s, the output frequency is 2 hz, and the signal coordinate values are set as shown in Table 2 below.

Table 2 pseudo-satellite coordinates

name	X(m)	Y(m)	Z(m)
P L01	-0.17	14.67	3.44
P L02	1.07	14.31	6.47
P L03	1.51	13.32	3.28
P L04	1.19	12.33	6.16
P L05	0.33	11.71	3.36
P L06	-0.99	11.84	6.26
P L07	-1.64	12.99	3.44
P L08	-1.38	14	6.33

2. simulation data setting: the data of ranging precision analysis is simulated by using single-channel three-frequency data, and the data loss and cycle-slip anomaly are simulated by setting L1 frequency point 1/3/5/7/8 signal loss at 10 seconds. At 13 s, the signal reacquisition is effective and the observation data are output. At 40s, the signal of B1 frequency point 7/8/10/11/13 loses lock, at 40.5 s, the signal of B1 frequency point 7/8 star reacquisition, and at 63 s, the signal of B1 frequency point 6/9/13 loses lock, 7/8/10/11/13 signals were lost at B1I and B3i frequency points at 70s, and reacquisition was effective at 73s. The rest of the time the data are normal.
3. In the random error simulation the phase error of the receiver output is generally 0.02 cycle. Here, the empirical value as the reference to complete the error simulation test within the range of 0.02~0.08.
4. The particle swarm optimization algorithm is initialized. We randomly generate 100 points within the range described above, set the particle velocity to vlimit = [-0.5, 0.5;-0.5, 0.5;-0.5, 0.5;] , set the inertia weight to w = [0.5; 0.5; 0.5], the self-learning factor c1 = [0.5; 0.5; 0.5], the population learning factor c2 = [0.5; 0.5; 0.5], set the iterations to 100, set the particle fitness initialized to 0, the particle best fitness initialized to 0, and the particle best position initialized to the position minimum point.

4.2. Analysis of phase error and ranging accuracy

It is found from the simulation data that when the carrier phase error is set in ± 0.01 range, the estimation of the whole cycle of ranging is almost all in 57, and there is a ± 1 week ranging error at some points When the carrier phase error is set in the ± 0.02 range, the whole-cycle estimation is similar to that when the phase is set in ± 0.01, only the partial data is more in the 56-week estimation; when the carrier phase error is in the ± 0.04 range, there are frequent fluctuations and multi-values in the whole-cycle estimation, and the maximum range estimation can be up to about 1 m, the data can guarantee more than 90% of the correct range estimation.This is shown in Figure 4.

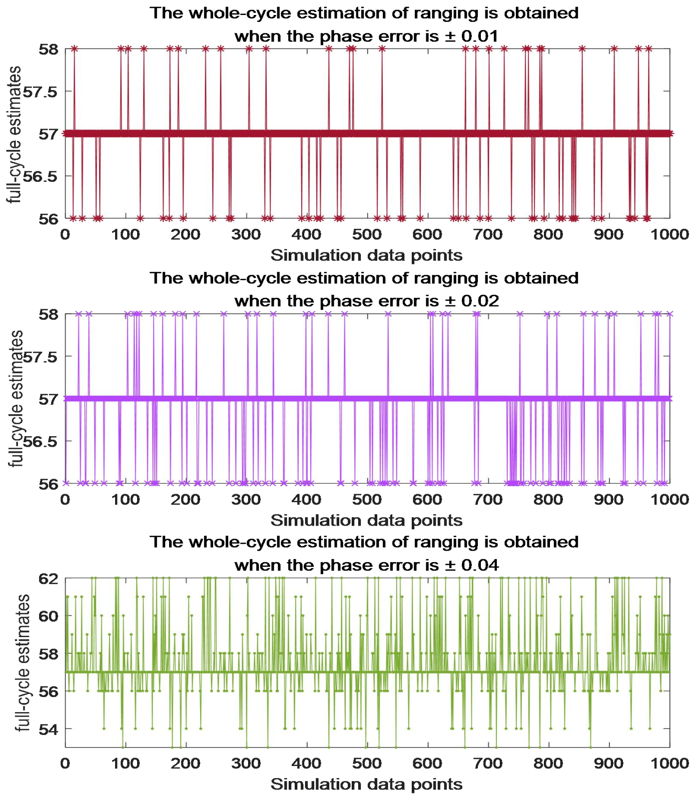

Figure 4: Estimation of ranging accuracy

4.3. Analysis of frequency points and ranging accuracy

Of the 1000 sets of simulation data analyzed in this section, 45% introduced a ± 0.04-week phase error and 55% introduced a ± 0.02-week phase error. The results show that: (1) the longer the wavelength of the two frequency signals, the more accurate the range estimation is; (2) increasing the frequency can effectively increase the accuracy of range estimation.This is shown in Figure 5.

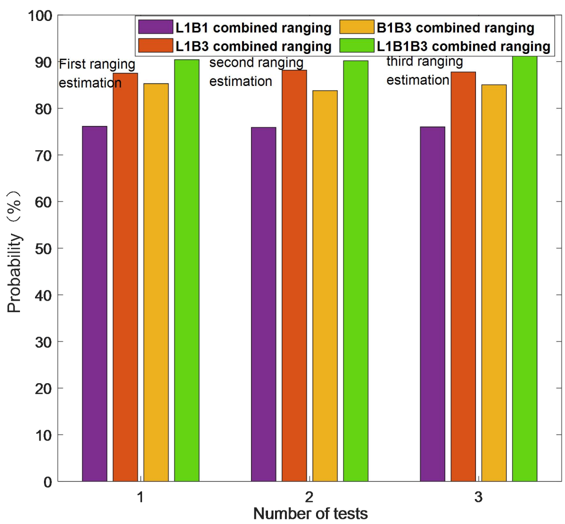

Figure 5: With any combination of frequency points, the whole-cycle estimation satisfies ±1 cycle probability

According to the simulation results, the original KPI-based Dopler localization algorithm can achieve the reusing of the signal data and participate in the localization for the instantaneous signal loss and recapture, but the data is continuously unavailable, compared with this algorithm, the proposed algorithm ensures the stability of the signal in continuity and location accuracy by multi-frequency constraint and abnormal signal reacquisition and repair.

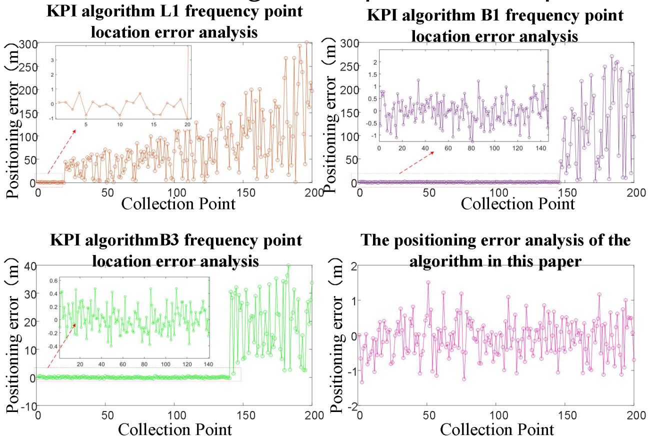

Figure 6: Location error analysis

5. CONCLUSION

In order to solve the problem of cycle slips in pseudolite indoor positioning, a new method based on multi-frequency constraint is Particle swarm optimization. This method avoids the ranging error caused by frequent cycle slips in indoor environment and time-based ranging problems such as Toa and TDOA. The signal transmission distance can be calculated by using the inter-cycle phase relation of dual-frequency signals, and then use the Particle swarm optimization for high-precision positioning. The algorithm can effectively improve the continuity of pseudolite signal in indoor location and phase recovery of signal recapture. The simulation results show that the multi-frequency constraint can not only improve the application of KPI algorithm for single signal lock-down and recapture, but also improve the ranging accuracy, the location continuity of the signal is further improved. However, the algorithm can not locate the signal if the dual frequency of the tracking signal is not satisfied, so the KPI algorithm has more advantages, on the premise of ensuring accuracy, the continuous availability of positioning is further improved.

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References

[1] Pei Ling, Liu Donghui, Qian Juchao. Review of indoor location technology and its application[J]. Navigation and timing, 2017, 4(03): 1-10.

[2] Yan Dayu, Song Wei, Wang Xudan, etc. A review of the development of indoor location technology in China [J]. Journal of Navigation and positioning, 2019, 7(04): 5-12.

[3] Deng Zhongliang, Yin Lu, Tang shihao, etc. Review of key technologies for indoor location [J]. Navigation and timing, 2018, 5(03): 14-23.

[4] Liu Jingbin, Zhao Zhibo, Hu Ningsong, etc. Summary and prospect of indoor high precision positioning technology [J] . Journal of Wuhan University Sciences (information science edition),2022,47(07):997-1008.

[5] Deng Zhongliang. Demonstration of key technologies and services for high-precision indoor and outdoor positioning and navigation in cities[J]. China's scientific and technological achievements,2015,(5):37-40.

[6] Zhang Shengjun, Lin Ruolin. The present situation of indoor positioning technology [J]. Mapping and spatial geographic information, 2018, 41(7): 128-131.
[7] Wang Congchao. Research on key technologies for wireless indoor location [D] Southeast University,2018.
[8] Zhang ran, song Lailiang, ran Longjun. Particle swarm optimization based ultra-wideband location algorithm in non-line-of-sight environment [J]. Sensors and microsystems.2017,36(09):117-120,124.
[9] Yang Ziyang, Wu Caizhang, Zhang Chi. Hybrid UWB indoor location algorithm based on Chan and improved UKF [J]. Combined Machine Tool and automatic machining technology,2020(12):65-69.
[10] Chen L, Kuusniemi H, Chen Y W, et al. Information filter with speed detection for indoor bluetooth positioning. Proceedings of 2011 International Conference on Localization and GNSS, 2011:47-52.
[11] Varsamous M, Antonakopoulos T. A bluetooth smart analyzer in iBeacon networks[C]. Proceedings of 2014 IEEE Fourth International Conference on Consumer Electronics, 2014,12: 288-292.
[12] Jiang Dexiang, Hu Mingqing, Chen Yiqiang, etc. Adaptive Bluetooth location method based on kernel ridge regression [J]. Computer Application Research, 2010, 27(9): 3487-3489,3492.
[13] Manandhar, D.; Okano, K.; Ishii, M.; Kogure, S.; Maeda, H. Development of ultimate seamless positioning system based on QZSS IMES. In Proceedings of the International Technical Meeting of the Institute of Navigation, Savannah, Georgia, 16–19 September 2008.
[14] Manandhar, D.; Kawaguchi, S.; Torimoto, H. Results of IMES implementation for seamless indoor navigation and social infrastructure platform. In Proceedings of the 23rd International Technical Meeting of the Satellite Division of the Institute of Navigation, Portland, OR, USA, 21–24 September 2010.
[15] Fujii, K.; Sakamoto, Y.; Wang, W.; Arie, H.; Schmitz, A.; Sugano, S. Hyperbolic Positioning with Antenna Arrays and Multi-Channel Pseudolite for Indoor Localization. Sensors 2015 , 15, 25157–25175.
[16] Fujii, K.; Yonezawa, R.; Sakamoto, Y.; Schmitz, A.; Sugano, S. A combined approach of Doppler and carrier-based hyperbolic positioning with a multi-channel GPS-pseudolite for indoor localization of robots.In Proceedings of the 2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN),Alcala de Henares, Spain, 4–7 October 2016; pp. 1–7.
[17] Sakamoto, Y.; Ebinuma, T.; Fujii, K.; Sugano, S. Doppler pose estimation using multiple IMES transmitters for indoor localisation. J. Locat. Based Serv. 2014, 8, 36–53.
[18] Niwa, H.; Kodaka, K.; Sakamoto, Y.; Otake, M.; Kawaguchi, S.; Fujii, K.; Kanemori, Y.; Sugano, S. GPS-based indoor positioning system with multi-channel pseudolite. In Proceedings of the 2008 IEEE International Conference on Robotics and Automation, Pasadena, CA, USA, 19–23 May 2008; pp. 905–910.
[19] Gan, X.; Yu, B.; Chao, L.; Liu, S. The development, test and application of new technology on Beidou/GPS dual-mode pseudolites. In Proceedings of China Satellite Navigation Conference (CSNC) 2015 Proceedings, Xian,China, 13–15 May 2015; Springer: Berlin/Heidelberg, Germany, 2015; Volum， 340, pp. 353–364.
[20] [9] Huang L , Gan X , Yu B , et al. An Innovative Fingerprint Location Algorithm for Indoor Positioning Based on Array Pseudolite[J]. Sensors (Basel, Switzerland), 2019, 19(20).
[21] Gan, X.; Yu, B.; Heng, Z.; Zhu, R.; Li, Y. Pseudolite cellular network in urban and its high precision positioning technology. In Proceedings of the China Satellite Navigation Conference (CSNC) 2017 Proceedings, Shanghai, China,23–25 May 2017; Springer: Singapore, 2017; Volume 437, pp. 313–324.
[22] Taejo of Goryeo, Zhang Xianzhou. GPS single epoch ambiguity search based on improved particle swarm optimization algorithm [J]. Science of surveying and mapping,2013,38(6):157-159.

[23] Zhai Yanrong, Huang Huan, Zhang Shen, etc. . Improved Particle swarm optimization for TDOA location [J]. Sensors and Microsystems,2013,32(4):145-148,152.